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TECHNICAL REPORT

AMRA TR 64-28

DEVELOPMENT OF A STRUCTURAL URANIUM ALLOY

by

JACOB GREENSPAN

and

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U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172

SEPTEMBER 1964

The findings in this report are not to be construed as an official Department of the Army position.

Uranium alloys

Alloys,
high density

Alloys,
high strength

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ABSTRACT

A uranium alloy is described, giving data on mechanical behavior and how it is affected by certain variations in alloy content and thermal history. The range in property values thus presented was considerable. The work described is associated with possible applications of depleted uranium for structural purposes.

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INTRODUCTION

Uranium, being one of the most dense metals in reasonable abundance, and showing considerable versatility in its alloying and processing characteristics, is potentially useful as a high density structural material. This usefulness, as set apart from the more familiar area of nuclear fuels, applies to depleted uranium, and may extend to many diverse applications.[1] For example, the work reported here is associated with structural components for some Army weapons systems, and pertains to the development of mechanical or structural properties for a uranium alloy.

Uranium combines readily with many metals and also exhibits phase transformation phenomena from which a wide variety of microstructures and properties may be derived. Familiar treatments such as solutionizing, quenching, aging, continuous cooling, isothermal transformation, etc., are applicable to the metallurgical engineering of many uranium base alloys. Of a number of uranium alloys tabulated in the existing literature,[2-5] one having composition U-2%Mo-2%Cb-2%Zr-1/2%Ti has exhibited some promising mechanical properties. The present work reports further investigation of this alloy with respect to composition, thermal history, and some aspects of the ensuing mechanical behavior. The extent of composition variation is detailed in Table I, and thermal history variations are described in the following text and summarized in Tables II and III. Given in this respect

Table I. VARIATIONS EXERCISED IN ALLOY COMPOSITION FOR ALLOY U-(K)% Mo-(K)% Cb-(K)% Zr-½% Ti

(K)% Nominal	Typical (K)% by Chemical Analysis			
	Mo	Cb	Zr	Ti
1	1.07	0.96	0.89	0.53
1¼	1.20	1.23	1.03	0.46
1½	1.54	1.48	1.38	0.48
2	2.04	1.96	1.74	0.49

(K)% having nominal values of 1, 1¼, 1½, and 2 applied singly to an individual alloy

are some tensile properties, impact resistance, hardness, and density, the extent of which is summarized in Figures 1 and 2. The range in property values thus presented is seen to be considerable, and the given data may provide a basis for "tailoring" property-density combinations as may be desired within this range.

PROCEDURES

General procedures consisted of composing alloy ingots by vacuum induction melting, extruding to rod, machining test samples, heat treating, and testing. The uranium melting stock employed was high purity AEC "dingot" or "derby" material, that is, extracted by direct reduction of uranium tetrafluoride. Purity of this uranium reportedly was of the order of 99.9%. The alloy materials employed were molybdenum pellet 99.95% pure, columbium

bar clippings 99.5% pure, zirconium sponge 99.5% pure, and titanium sponge 99% pure. Melting was accomplished in a zirconia-lined graphite crucible in a vacuum furnace, and lip-poured within the furnace in molds of the same material as the melting crucible. Ingots were scalped to 60-pound size, canned in copper, and extruded to ¾-inch-diameter rod, the extrusion temperature being 1650 F (900 C), and the extrusion reduction ratio about 16 to 1.

Tensile and Charpy blanks were rough machined from extruded stock, heat treated, and then finish machined. Experimental thermal treatment was carried out on material in the as-extruded condition, and consisted of solutionizing followed by aging. Both were done in vacuum of about 10^{-5} mm of mercury. Solutionizing was accomplished by heating well into the gamma region to temperatures of the order of 1750 F (954 C), holding for 4 to 8 hours, and then quenching in water. Aging consisted of heating to temperatures from 400 F to 600 F (205 C to 316 C) holding for 4 to 8 hours, and furnace cooling. Tensile testing was done on a 120,000-pound hydraulic machine, equipped with extensometer attachments, and autographical load-strain recording device. Impact resistance was determined by a self-recording, swinging pendulum-type impact machine, with the sample at -40 F, this convention being maintained for comparative purposes with past data.

RESULTS

In accordance with the most significant aspects of the test data, results are arranged to show the influence of each of the principal independent variables, alloy content and thermal history. Insofar as alloy content was pursued, its effects are shown in Figure 1 and Table II, which

Table II. DATA FOR URANIUM ALLOY GROUP
U-(K)% Mo-(K)% Cb-(K)% Zr-½% Ti IN
AS-EXTRUDED CONDITION

Property	Alloy Identification*			
	(K) = 1	(K) = 1¼	(K) = 1½	(K) = 2
Modulus of Elasticity (millions of psi)	19.6	20.3	20.7	14.8
Yield Strength, 0.01% Strain Offset (ksi)	99.0	121.0	134.0	129.0
Yield Strength, 0.02% Strain Offset (ksi)	108.0	134.0	160.0	140.0
Yield Strength, 0.1% Strain Offset (ksi)	149.0	186.0	227.0	188.0
Yield Strength, 0.2% Strain Offset (ksi)	174.0	213.0	254.0	216.0
Ultimate Tensile Strength (ksi)	247.0	263.0	308.0	239.0
Fracture Strength (ksi)	318.0	328.0	332.0	260.0
Elongation in 1-inch (Percent)	8.2	6.5	3.0	3.9
Reduction of Area (Percent)	22.0	16.5	8.9	9.2
Impact Resistance, Charpy, -40 F (Ft-Lb)	4.0	3.9	3.9	3.3
Hardness, Rockwell C	49.1	51.0	55.6	49.0
Density (g/cm^3)	17.9	17.8	17.68	17.4

*(K) denotes weight percent of each of the principal alloy elements Mo, Cb, and Zr
Each value given is an average of 4 or more tests

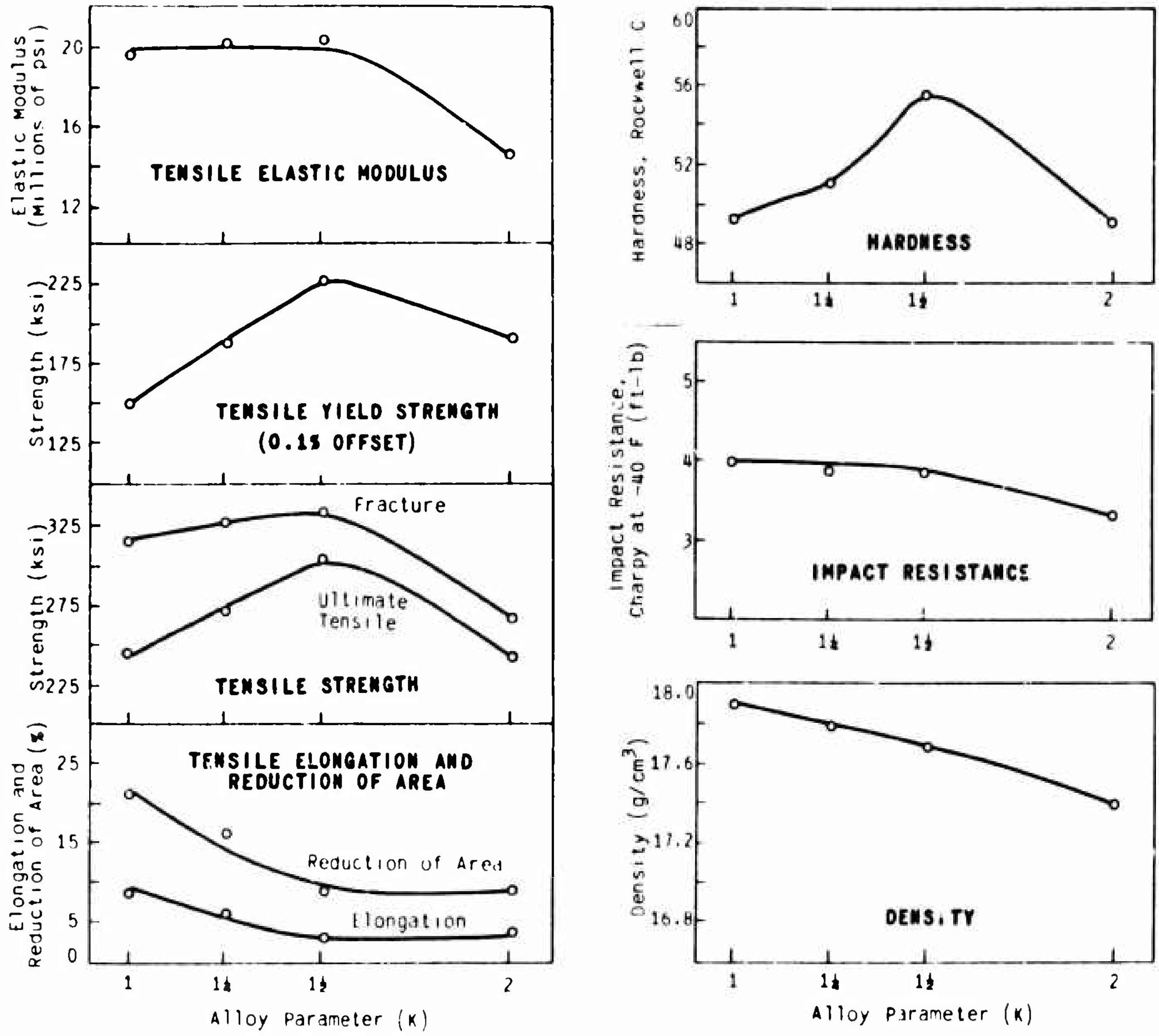

Figure I. MECHANICAL PROPERTIES VERSUS ALLOY CONTENT PARAMETER (K) IN URANIUM ALLOYS OF COMPOSITION U-(K)% Mo-(K)% Cb-(K)% Zr-1/2% Ti HAVING (K) VALUES FROM 1 TO 2. ALL SAMPLES WERE IN AS-EXTRUDED CONDITION. SEE TABLE II FOR DATA.

represent only material in the as-extruded condition. Thermal history was practically the same for all samples and therefore alloy content is regarded as the factor which influences the indicated properties.

As explained in Table I the variability in alloy content is given by the change in content of the principal alloy elements Mo, Cb, and Zr, where for any particular case the nominal weight content of each of these elements was the same. More conveniently, if the alloy is expressed as U-(K)% Mo-(K)% Cb-(K)% Zr-½% Ti the parameter for variability in alloy content is given by (K). Plotted against (K) in Figure 1 are test values (see Table II) of the following properties when (K) had values from 1 to 2: modulus of elasticity in tension; yield strength for 0.1% offset strain; tensile strength (ultimate load on initial cross-sectional area); fracture load (fracture load on final cross-sectional area); elongation; reduction of area; impact resistance; hardness; and density.

An outstanding trend, shown by Figure 1 and Table II, is the optimum strength and hardness which occurred for a (K) value of 1½. However, optimum ductility, as given by percent reduction of area and percent elongation, occurred for a (K) value of 1. Consequently, fracture strength, calculated on the basis of cross-sectional area at fracture, was nearly the same for (K) values of 1 to 1½. Those strengths which exceed 300,000 psi are believed to be the highest now known among uranium base alloys. Impact resistance was greatest for (K) values of 1 to 1½, being significantly lower for a (K) value of 2. It is seen therefore that the best combinations of yield strength and impact resistance for extruded material occurred when (K) was in the range of 1 to 1½, but particularly when (K) was 1½. Density, ranging from 17.9 to 17.4 grams per cubic centimeter, decreased almost linearly with increasing (K), as expected. Modulus of elasticity was nearly unchanged for (K) of 1 to 1½, having about the same value as that listed for unalloyed alpha uranium. The modulus of elasticity was considerably lower when (K) was 2, thus implying the retention of some of the gamma (body-centered cubic) uranium phase, which is known to have a lower modulus. However, such retention is not yet confirmed by X-ray analyses.

The effects of heat treatment, with respect to solution treating and aging temperature are given in Figure 2 and Table III, where (K) parameters are separated when significant. The outstanding general trend is the extensive softening produced by solutionizing, and the effective hardening produced by aging. Also, when the material was in the soft condition, impact resistance was highest and yield strength lowest, but opposite trends became established as age hardening took place. Thus, the combination of high impact resistance together with high yield strength, which is important to many structural applications, appeared in principle to be unobtainable. However, with respect to each of these two properties, alloys with (K) values of 1 to 1½ were generally superior to those with a (K) value of 2. The trend for this combination is more clearly indicated by means of their product, arbitrarily called a "dynamic structural factor", in Figure 2. This parameter is used only as a means of differentiation among the subject alloys. It is not to be regarded as a general design parameter. When the

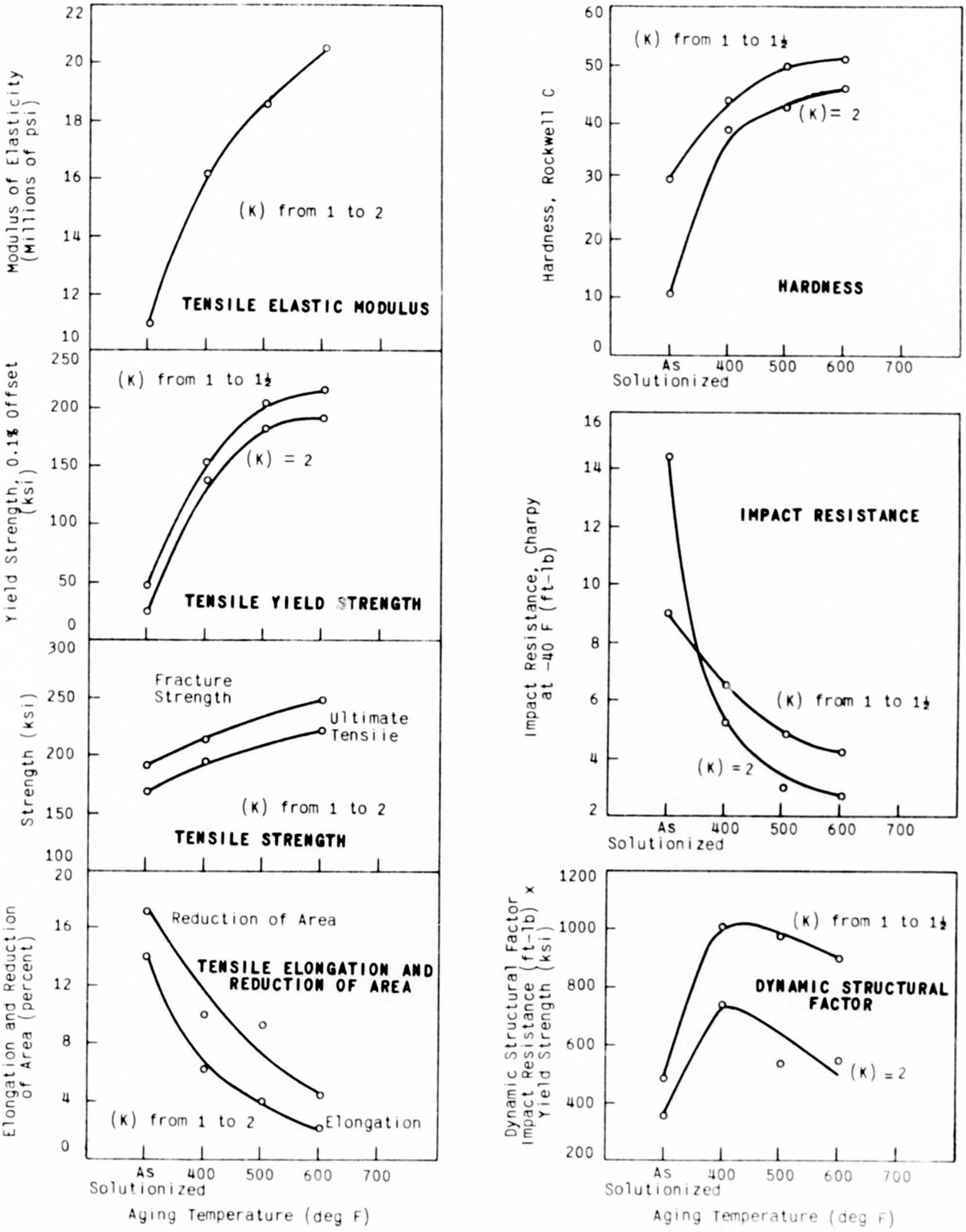

Figure 2. MECHANICAL PROPERTIES VERSUS AGING TEMPERATURE FOR URANIUM ALLOYS OF COMPOSITION U-(K)% Mo-(K)% Cb-(K)% Zr-1/2% Ti HAVING VALUES OF (K) FROM 1 TO 2. SAMPLES WERE EXTRUDED, SOLUTIONIZED, AND AGED WITH AGING TIME OF 4 TO 8 HOURS. SEE TABLE III FOR DATA.

Table III. DATA FOR URANIUM ALLOY GROUP HEAT-TREATED AS SHOWN
U-(K)% Mo-(K)% Cb-(K)% Zr-½% Ti*

	As-Solutionized			Aging Temperature								
				400 F			500 F			600 F		
(K)	1 to 2	1 to 1½	2	1 to 2	1 to 1½	2	1 to 2	1 to 1½	2	1 to 2	1 to 1½	2
Modulus of Elasticity (millions of psi)	10.6	11.3	9.5	16.2	16.8	14.5	18.5	19.5	17.6	20.3	21.6	19.1
Yield Strength, 0.1% Offset (ksi)	43	49	25.6	15.1	155.3	140	190	207	174	210	215.3	194
Ultimate Tensile Strength (ksi)	164	173	138	192	197	175	202	234	189	246	251	232
Fracture Strength (ksi)	189	193	178	214	212	218	235	261	210	251	258	228
Impact Resistance, Charpy, -40 F (ft-lb)	10.6	9.3	14.4	6.2	6.5	5.3	3.8	4.7	3.0	3.9	4.2	2.9
Hardness, Rockwell C	20	31	10	43	44	39	48	50	43	49	51	46
Elongation (percent)	14	11.9	18	5.1	4.8	6	3.7	3.5	4	2	1.3	3
Reduction in Area (percent)	16.5	14.6	22.4	9.8	7.3	17.6	10.0	8.9	11.2	4.2	3.5	8
Dynamic Structural Factor (Yield Strength x Impact Resistance)		441	368		1007	742		973	522	903		562

*(K) denotes weight percent of each of the principal alloy elements Mo, Cb, and Zr
Each value given is an average of 4 or more tests

material was in the soft condition, ductility was highest, modulus of elasticity lowest, and ultimate strength lowest. When the material became hardened, strength increased, and modulus of elasticity increased, but ductility decreased.

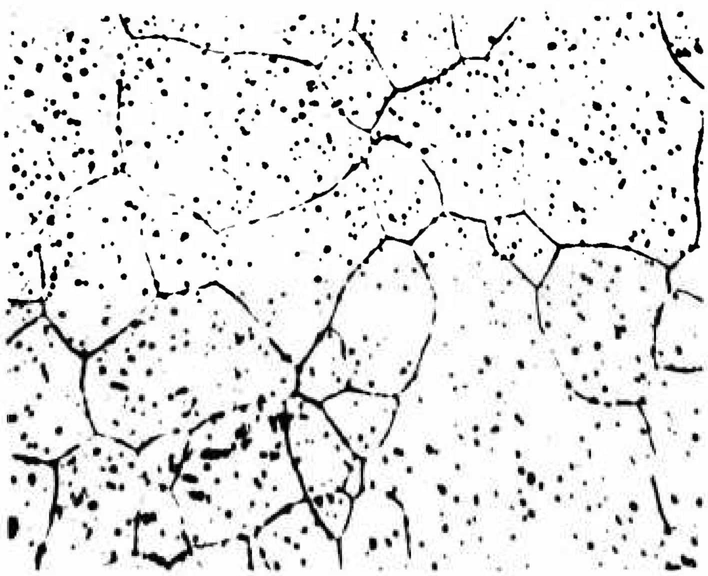

Figure 3. MICROSTRUCTURE FOR URANIUM ALLOY, U-(K)%Mo-(K)%Cb-(K)%Zr-½%Ti, (K) - 2, THERMAL HISTORY EXTRUDED AND SOLUTIONIZED. MICROSTRUCTURE IS GENERALLY REPRESENTATIVE OF ALLOYS STUDIED.

Analyses for crystallographic phase identification have thus far shown only the existence of alpha, regardless of those thermal histories given in the present work. It is known however, that additional phases can be produced by other thermal treatment.[6] Structure of the alpha as deduced from X-ray diffraction traces was identified as distorted orthorhombic. No other crystallographic phase was detected. Metallographic observation, such as the typical example shown in Figure 3, also indicates primarily single-phase structure.

CONCLUSIONS AND REMARKS

The range in property values exhibited in Tables II and III is of considerable breadth. This can be viewed more simply by examining only three representative cases of mechanical behavior, given roughly in Table IV as soft, intermediate, and hard. The upper limit of fracture strength, 332,000 psi, is noted particularly, since this is certainly among the highest known for uranium alloys. Table IV is of convenience also when associating the materials with further processing operations, or with specific applications requirements. Examples are as follows: the soft condition for cold work processing; the soft condition for low yield point and/or high impact resistance requirements; the intermediate condition for optimum combinations of high yield point with good impact resistance; the hard condition for requirements of high modulus, very high yield point, and/or very high hardness.

Table IV. DATA FOR URANIUM ALLOY GROUP
U-(K)% Mo-(K)% Cb-(K)% Zr-½% Ti*
Summary With Respect to Three Conditions of Mechanical Behavior

		Condition		
		Soft	Medium	Hard
	(K) Value	2	1	1½
Property	Thermal History	Solutionized	Solutionized and Aged, 400 F	As-Extruded
Density, grams per cm^3		17.4	17.9	17.6
Modulus of Elasticity (millions of psi)		9.0	17.0	21
Yield Strength, 0.1% Strain (ksi)		23.0	172	224
Ultimate Tensile Strength (ksi)		135	206	308
Fracture Strength (ksi)		180	238	332
Elongation (percent)		24	6.0	2
Reduction of Area (percent)		27	13	11
Hardness, Rockwell C		10	47	57
Impact Resistance, Charpy, -40 F (Ft-Lb)		14.6	6.1	4.0
Dynamic Structural Factor (Yield Strength x Impact Resistance)		336	1050	896

*(K) denotes weight percent of each of the principal alloy elements Mo, Cb and Zr

The subject alloys thus far defined are able to contribute to areas requiring high density together with specific structural properties. The state of knowledge of the particular alloys, with respect to their physical metallurgy, at present is relatively inextensive. Thus further possible developmental potential is indicated for them as well as other related uranium alloys.

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